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ABSTRACT

The investigation reported in this monograph represents an attempt to establish the abilities, attitudes, and activities which go toward making an effective industrial scientist and to determine how and to what extent these factors should influence the design of undergraduate courses and the various aspects of career guidance. The views of nearly 1,400 British scientists were assessed and results presented that show the level of usefulness of various subjects and techniques to these scientists, and the extent to which they received instruction in these topics during their undergraduate training. Opinions concerning the desirable attitudes of an industrial scientist and the particular attributes that scientists occupying various specific positions should possess are also recorded. The results of the enquiry show that the practicing industrial scientist believes that much can be done to improve course design, not only to enhance the technical competence of the student, but also to make a career in industry a more attractive and worthwhile proposition. (Author/AF)

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THE EDUCATION OF SCIENTISTS FOR INDUSTRY

Report of a Survey of the Views of
Professional Scientists

by

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3

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PREFACE

The investigation reported in this monograph represents an attempt to establish the abilities, attitudes and activities which go towards making an effective industrial scientist and to determine how and to what extent these factors should influence the design of undergraduate courses and the various aspects of career guidance.

The views of nearly 1,400 professional scientists are assessed and results presented which show the level of usefulness of various subjects and techniques to these scientists, and the extent to which they received instruction in these topics during their undergraduate training. Opinions concerning the desirable attitudes of an industrial scientist and the particular attributes which scientists occupying various specific positions should possess are also recorded. The results of the enquiry show clearly that the practising industrial scientist believes that much can be done to improve course design, not only to enhance the technical competence of the student but also to make a career in industry a more attractive and worthwhile proposition.

This monograph was edited for publication by Dr. R. Oxtoby, formerly Organising Secretary, Society for Research into Higher Education. In publishing the monograph, the Society hopes that the results of the survey will be of value to anyone involved in discussions of the scope and content of undergraduate courses in science and technology. The author has himself prepared an outline of a course which tries to incorporate the main features of these results and will be glad to discuss this with interested readers.

ACKNOWLEDGEMENTS

Ideas are neither sown nor matured in isolation and I would like to thank my former colleagues in the Science Department at Hendon College of Technology for providing stimulating discussions and support for me in this project.

The punched cards used in the analysis were produced by members of the laboratory staff at Hendon and I am grateful for their co-operative efforts in saving both time and money. Members of the laboratory staff also transferred the coded information to the cards and made the appropriate slots, showing admirable endurance in the performance of this long and tedious task.

Several people made useful suggestions during the final stages of designing the questionnaire. I am especially grateful to R. P. D. van Rossum, MA who spent much spare time in acquainting me with the methods of market research and helping to design the basic form of the questionnaire.

The draft of this report was read by Dr. B.C. Cox, BSc, FRIC and Dr. N. Chamberlain, BSc, FRIC, MIBiol, and I am grateful for their helpful comments.

January 1969 DTLJ

CONTENTS

LIST OF TABLES

SCOPE OF THE ENQUIRY

The Questionnaire

One of the major problems facing the investigator embarking on an enquiry of this nature is to establish the precise form of the questions to be asked. Two factors need to be taken into account. In the first place, the investigator, being deeply concerned with the topic under investigation, has preconceived ideas about possible solutions and is in danger of leaving unexplored areas which he considers to be less significant. Secondly, because of the complexity of the enquiry and the limited nature of any one person's experience, specific topics of interest may well be overlooked.

In designing the form of the questionnaire (Appendix 1), consultations were held with industrial scientists, scientists in academic positions who had spent some time in industry and some who had not worked in industry, business people who were non-scientists and non-scientists in academic positions. Although account could not be taken of all their suggestions, mainly because of limited space, the overall area of coverage met with their general approval. The questionnaire plainly indicates that extra written evidence would be welcomed and, where appropriate (questions 1, 2, 5, 7 and 8), suggestions of topics and matters which would be of relevance but are not specified on the form have been encouraged. In these ways it was hoped to obtain an indication of most of the factors which have a boaring on the investigation.

The significance of information spontaneously offered in answer to these open-ended questions and in accompanying letters is, however, unknown as a result of this enquiry. The impact that this information should make on future course design is therefore uncertain. Consequently, it was apparent in the early stages of the project that a follow-up enquiry would be desirable to assess the importance of these additional matters and to obtain more specific information concerning the details of an appropriate course design. This report is concerned solely with the information obtained from the initial enquiry.

Attention must be paid to several areas of concern in designing a course suitable for the prospective industrial scientist. The planner must be aware, for example, of those subjects and techniques which play a part in the activities of the industrial scientist outside those contained in his speciality. Question 2 is designed to reveal these areas, but it is not intended to imply that all useful subjects and techniques should necessarily be included in an undergraduate course. Conventional courses may take adequate notice of some of these topics and it is of interest to know to what extent they are already covered. Such information is revealed by the answers to question 3.

If more material is to be included in courses, then they must be either lengthened and/or have some of the conventional content replaced by new subjects.

Scientists' views regarding desirable modifications to courses in this respect are expressed in answer to question 4. If abridgement is desirable, either to make room for more relevant material or simply to remove 'dead wood' for more effective use of educational time, the views of scientists who are in a position to reflect on the limitations or strengths of their own undergraduate training are highly relevant. Such views are presented in answer to question 5.

Finally, opinions regarding the general approach to the ideal course in areas not directly concerned with subject matter, such as approach to practical work, time allocations to different activities, industrial involvement and teaching methods are expressed in answer to question 8. An opportunity is also presented here for the scientist to indicate whether subjects such as those in question 2, or any others he cares to suggest, should be included in a course for the industrial scientist.

Questions 1 and 7 are directed more towards a concern with career guidance, although the information resulting from them is pertinent to course design and needs to be considered in arriving at any overall conclusions.

The Sample

Ideally the answers would be obtained from a large, randomly selected sample of industrial scientists. This would require knowledge of the names and addresses of all industrial scientists in Britain, a situation beyond the scope of this investigator. The best alternative seemed to be to distribute as many copies of the questionnaire as possible and to hope that the returns would be meaningful both in terms of number and content. 24,000 copies of the questionnaire were distributed: 12,000 by the Institute of Physics in the Bulletin[1], and 12,000 by the Royal Institute of Chemistry in Chemistry in Britain[2]. Complete coverage was obtained over the membership of the Institute of Physics and arrangements were made to place copies in approximately half of the chemistry journals in a haphazard manner. Not more than 200 copies were also distributed to individuals and organisations and the percentage returns were approximately the same as those achieved with the journal distributions.

The number of returns used in the analysis amounted to 1392, representing a 6.1% return from the physics distribution and a 5.5% return from the chemists.

Whilst recognising the selectivity imposed by limiting distribution to the membership of the professional institutes and being aware of the uncertainty in the factors prompting individuals to reply, it is interesting to compare the distribution of returns with respect to nature of employment with the national distribution[3] for 1965. Under the heading of 'Others' in Table 1, are included scientists employed in government organisations, nationalised industries, research associations and public corporations. These categories are grouped here and elsewhere since the component numbers are small and because the aim is to distinguish the views of those scientists who are clearly in a competitive industrial environment.

Table 1. Distribution of physicists and chemists nationally and in the sample, expressed as percentages.

		Education	Industry	Others	Total
Chemists	National	30.8	55.7	13.5	31,582
	Sample	8.0	82.7	9.3	647
Physicists	National	45.8	32.5	21.7	16,336
	Sample	14.8	64.3	20.9	695

In addition, there were replies from 36 students of physics and 14 students of chemistry, and these included PhD students as well as undergraduates.

The sample is clearly biased towards scientists in industry, mostly at the expense of those in education but, since evidence was required concerning desirable course design for the scientist in industry, the survey was directed principally at this group, and this was clearly implied on the questionnaire although responses from other quarters were encouraged.

Method of Analysis

The questionnaire indicates that the information given should relate specifically to the scientist in industry. In analysing the results, regard must be paid to the source of information in so far as it might be expected to affect the interpretation of the data received. For example, one would certainly expect chemists to suggest different topics for inclusion in, or omission from, courses than physicists. One might also expect chemists to suggest different desirable attitudes for industrial scientists. The results from physicists and chemists have therefore been analysed separately.

The length of time the respondent has been in industry may also affect his replies. During his initial period in industry he will be reacting to his new environment, his academic conditioning may still prevail, he is still finding his way around his job and adjusting to more adult relationships and industrial responsibilities. He may also be looking for another job. To account for this transient stage he has been placed in a category with others who have spent up to three years in industry. After three years or so the industrial scientist is consolidating his position, has possibly made a well considered first change of job and has 'found his feet'. He will now be revising his initial views of industry and during, say, the next ten years will establish a fairly permanent outlook. The next category, therefore, covers those who have spent more than three and up to thirteen years in industry. The group with more than thirteen years in industry is seen as having a mature, unchanging outlook of industry and the needs of the industrial scientist.

Scientists who are not in industry and who have never been in industry form another category, whilst their colleagues who have spent some time in industry join categories which depend on the length of time in industry.

The definition of industry to exclude nationalised industries and other organisations indicated earlier, which is applied in this analysis, was not specified on the questionnaire and it was clear that several scientists who came under the heading 'Others' in Table 1 consider themselves to be in industry and indicated their number of years in 'industry' in the appropriate box. These have been grouped in a category described as 'history unknown'. Among the responses to the physics questionnaire, 49 indicated professions such as electronic engineer, electrical engineer, computer programmer and mathematician, and 16 replies to the chemistry distribution indicated chemical engineer or microbiologist as profession. Whilst these replies are valued and the comments have been used in the analyses they have been included in categories labelled non-physicist and non-chemist, there being uncertainties about the nature of their undergraduate training.

Finally, it is reasonable to suppose that the position of the scientist will influence his responses. An attempt has been made to take account of two variables here in distinguishing between what are called 'technologists' and 'non-technologists', on the one hand, and 'managers' and 'non-managers' on the other. In the technologist group are included scientists who apply their scientific training in relation to some laboratory activity, those involved primarily with research and development or similar practical, scientific endeavours. Non-technologists will be primarily concerned with management, marketing, training or similar activities in which practical scientific activity plays a less prominent role. This can, of course, be regarded as a rough division only, in so far as job titles mean different things in different organisations and, in several cases, the classification is somewhat arbitrary.

One might expect that emphasis in the replies will depend not only on the type of job in terms of technical involvement but also in terms of the managerial responsibility of the respondent. In this respect an attempt has been made to distinguish between those who have significant management responsibilities in that they direct the activities of graduates, and those who may be said to be managed. Here again the job title is very much dependent on the organisation, especially with regard to its size and type of activity but, as a general guide, the title of 'section head' has been chosen as the lowest level in the management category. The classifications according to title are illustrated in Appendix 2. Classifications were based not only on information given in response to the questionnaire, but also on reference to the company address (80% of the physicists and 75% of the chemists gave an address) and, where necessary, on reference to the membership lists of the appropriate Institute (88% of the physicists and 85% of the chemists gave their names).

The result of the classification is that each sample of physicists and chemists is divided into the 19 groups as shown in Table 2.

Table 2. Classification, showing group descriptions.

	GROUP	YEARS IN INDUSTRY	STATUS
NON-INDUSTRIAL	A B C D	0 less than 4 4 to 13 inclusive more than 13	Managerial
	E F G H	0 less than 4 4 to 13 inclusive more than 13	Non-Managerial
	I	history unknown	Managerial
	J	history unknown	Non-Managerial
INDUSTRIAL	K	not classified	Non-Managerial Non-Technologist
	L M N	less than 4 4 to 13 inclusive more than 13	Non-Managerial Technologist
	O P Q	less than 4 4 to 13 inclusive more than 13	Managerial Technologist
	R	not classified	Managerial Non-Technologist
	S	not classified	Non-Physicist or Non-Chemist

The membership of Groups K, R and S was considered too small to justify further subdivision according to years in industry. It should be noted, however, that in Group R (physicists 42, chemists 55) 79% of the physicists and 69% of the chemists had spent more than 13 years in industry and 19% of the physicists and 31% of the chemists had spent 4 to 13 years in industry. We can, therefore, treat Group R as consisting of well-experienced industrialists. In Group K (physicists 12, chemists 19) for years in industry of more than 13, and 4 to 13, the corresponding percentages are physicists 42 and 42 and, for the chemists, 32 and 53, the remainder in both cases having more than three years in industry, suggesting that the non-technologist spends his initial years in a technological situation.

Table 3. Group characteristics expressed as percentages of total group membership, for physicists and chemists.

Chemists
Physicists

GROUP		TOTAL	QUALIFICATION			TYPE OF TRAINING		AGE				
			PhD	BSc MSc	Other	Univ.	Tech. CAT	Less than 26	26-30 incl.	31-36 incl.	More than 36	Not given
NON-INDUSTRIAL	A	9	67	33	0	89	11	0	11	11	67	11
		15	53	47	0	87	13	0	0	7	80	13
	B	4	100	0	0	100	0	0	0	0	100	0
		9	67	33	0	89	11	0	0	0	100	0
	C	6	67	33	0	83	17	0	0	17	83	0
		14	29	71	0	86	14	0	7	7	79	7
	D	5	60	40	0	100	0	0	0	0	100	0
		15	47	53	0	93	7	0	0	0	100	0
	E	27	33	52	15	78	22	44	22	15	15	4
		71	20	70	10	83	17	41	24	17	17	1
	F	16	38	50	13	81	19	31	0	38	19	13
		40	20	75	5	80	20	25	25	13	25	10
	G	23	35	39	26	57	43	13	13	17	57	0
		58	29	62	9	84	16	5	26	16	48	5
	H	11	27	64	9	55	45	0	0	0	100	0
		10	50	50	0	80	20	0	0	0	100	0
	I	8	0	75	25	50	50	0	0	13	88	0
		21	24	71	5	86	14	0	0	19	81	0
	J	12	17	33	50	33	67	0	33	17	50	0
		19	21	63	16	79	21	5	16	16	47	16
INDUSTRIAL	K	19	16	58	26	68	32	11	37	21	32	0
		12	8	92	0	75	25	0	25	42	33	0
	L	34	38	53	9	82	18	62	32	6	0	0
		69	7	90	3	88	12	83	10	3	0	4
	M	110	22	31	47	45	55	15	52	25	7	2
		90	12	67	21	69	31	19	44	21	13	2
	N	74	18	55	27	41	59	0	0	15	85	0
		46	17	78	4	85	15	0	2	7	87	4
	O	6	17	33	50	50	50	83	17	0	0	0
		3	100	0	0	100	0	0	33	33	0	33
	P	58	41	36	22	67	33	3	28	31	29	9
		46	33	63	4	91	9	4	9	46	37	4
	Q	168	24	58	18	57	43	0	1	6	92	2
		102	20	75	5	77	23	0	0	7	90	3
	R	55	25	67	7	71	29	0	7	13	80	0
		42	10	81	10	79	21	2	2	5	83	7
	S	16	19	63	19	69	31	0	0	19	81	0
		49	16	73	10	63	37	14	22	24	31	8
TOTAL		661	27	49	23	59	41	10	17	15	56	2
		731	21	71	8	80	20	17	16	15	48	5

Note: 'Other' qualifications include HNC, HND and Graduate and Licentiate membership of Institutes obtained by examination.

Table 3 shows the characteristics of each group in terms of age distribution, academic qualifications, and whether qualifications were obtained at a university, at a technical college or at a college of advanced technology.

Although extreme caution must be exercised in drawing conclusions about national characteristics from this table, it does show that, in comparing results from different groups, attention must be paid to group characteristics besides those described as type of work, industrial experience and position held. We see, for example, that the concentration of PhDs amongst non-industrial managers in physics and chemistry is generally much higher than in other groups. Few of them obtained their qualifications outside the universities and they are mostly over thirty-five years of age. As one would expect for industrialists, more years in industry corresponds to a swing to higher age groups, and the same tendency occurs with non-managerial non-industrialists. Amongst non-managerial physicists, increased industrial experience both in industrialists and non-industrialists who have been in industry, corresponds to increasing concentration of PhDs while there is a reversed tendency for corresponding groups of chemists. Furthermore, for non-managerial chemists both in industrial and non-industrial positions, the concentration of those educated elsewhere than in the universities increases with industrial experience. The overall sample of chemists does contain, in fact, a much greater percentage of members educated in technical colleges and colleges of advanced technology and having Institute examination qualifications than the physicists, whilst the age distributions show a slight tendency towards youth amongst the physicists with a detectable increase in reluctance to divulge their age.

Whilst the sample has been classified according to discipline, type of work, industrial experience and position held, it is clear that other variables can be expected to play a part in influencing the results. Thus, age must surely influence attitudes and suggestions regarding course content which, to some extent, will be prompted by the reaction of the respondent to his own training. Experience of postgraduate academic work may also influence the replies as well as type of undergraduate training, and the type of industry to which the scientist is attached will inevitably determine to some extent the attitudes of the respondent and his conclusions regarding the limitations or advantages of his own training. Table 3 shows that some of these factors are not randomly distributed throughout the sample and there is little doubt that other relevant, but uncontrolled, and unrandomised variables attach to the sample. It would therefore be misleading to conduct statistical tests of significance in an attempt to expose differences in groups which are not attributable to random errors when the groups themselves contain non-randomised variables which are not identified by the group description. The general problem of applying statistical tests to non-experimental studies of this nature has been fully discussed by Selvin[4] who concludes that in such cases, tests of statistical significance are entirely unsuitable.

In the light of these considerations it was decided not to apply the statistical tests of significance usually adopted in experimental studies, but rather to attempt to expose inconsistencies in the results which may affect their interpretation. There are two types of data resulting from the survey. That which applies to the yes/no type of question will be expressed as the percentages of respondents who answered 'yes' or 'no' and the meaningfulness of the information will then be assessed in each case.

The open-ended questions, however, present more difficult problems. Firstly, not everyone in the sample attempted to answer each open-ended question, and, secondly, the classification of the answers is necessarily arbitrary; uncertainties in the statistics result from those in the respondent's interpretation of the question, the analyst's interpretation of the answer and the location of the answer in an appropriate category. Thirdly, since the respondent will presumably indicate in his answer that area which he considers to be most important at that point in time, it cannot be concluded that he considers other possible answers unimportant, or even less important at other times. It follows that measurements of the relative importance of each category in terms of its population are unreliable. Whilst it would seem reasonable to assume that the most heavily populated categories are important, it cannot be assumed that the categories with small populations are unimportant.

In analysing the results, a specific attempt will be made to reveal any obvious trends in the replies which can be associated with the type of work, length of industrial experience or status of the respondent. The influence of age may be indicated in certain areas. Reference to Table 3 shows that in Groups E, L and M the bulk of the physicists are under 30 years of age, and these will be referred to collectively as 'young physicists'. 'Young chemists' will be those contained in Groups E, L, M and O. Groups A, B, C, D, H, I, N, Q and R contain a large majority of physicists over the age of 36 and these will be referred to as 'old physicists'. 'Old chemists' will be those in Groups A, B, C, D, H, I, N, Q, R and S. Because of the nature of the sample and the approach to the analysis, trends indicated along these lines can only lead to tentative statements, but they should expose influences that will be of concern in future investigations.

RESULTS OF THE SURVEY

1. Techniques and Subjects of Use to the Industrial Scientist

The overall percentages of physicists and chemists who indicated that they felt the various techniques and subjects listed in question 2 to be useful in the light of their industrial or other experience are shown in Table 4. A more detailed breakdown is shown in Appendix 3. A comparison of levels of usefulness to physicists and chemists becomes clearer when the topics are arranged in identifiable groups.

(a) The subjects concerned with communication are found to be equally useful to scientists of both disciplines in the order: report writing (93%), verbal delivery (77%), and conversational foreign language (chemists 39% and physicists 35%).

(b) Similar levels of usefulness for chemists and physicists are generally expressed for topics concerned more directly with the technological activities of scientists. The results for chemists and physicists respectively are: statistical analysis (67%, 70%), project planning (64%, 67%), literature searching (69%, 62%), laboratory design (41%, 40%), critical path analysis (31%, 31%), operational research (28%, 31%) and information theory (17%, 17%). Physicists, however, declare more usefulness for computer technology (39%, 65%).

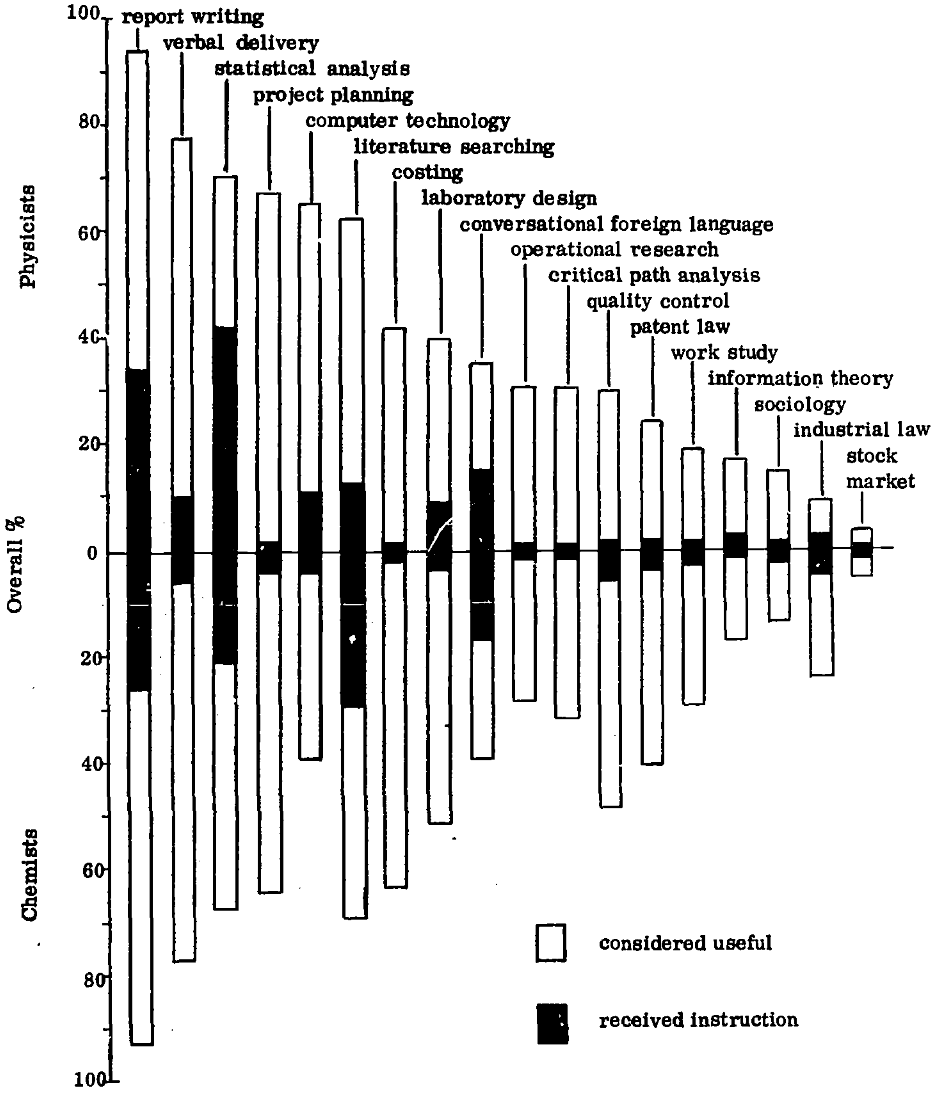
(c) Chemists claim more usefulness for subjects which may be said to have a more commercial bias: costing (63%, 42%), quality control (48%, 30%) and work study (29%, 19%).

(d) The remaining four subjects can be classified as concerning business knowledge and the chemists find more use for patent law (40%, 24%), and industrial law (24%, 9%), than do the physicists. Sociology, which is included in this group with some hesitation, is found to be useful by 15% of the physicists and 13% of the chemists, whereas the stock market is of little use to either physicists (3%) or chemists (5%).

Also shown in Table 4 are the overall percentages of physicists and chemists who claim to have received instruction in the various topics during their period of academic training as indicated in answer to question 3. 34% of all of the physicists and 46% of the chemists indicated that they had received no instruction in any of the topics during the period of academic training.

In answering question 2, scientists were invited to indicate additional topics which they considered to be useful in the light of their professional pursuits.

Table 4. Percentages of scientists who consider various topics to be useful, and percentages who received instruction in them.



Of all the physicists, 30% made a contribution and 31% of the chemists suggested other topics. The answers fall mainly into four categories which reflect the different aspects of the activities of the industrial scientist. These can be generally described as those techniques and subjects concerned with:

(a) management and organisation in industry (physicists 31%, chemists 40%), e.g. management theory, economics, marketing, project evaluation and decision making;

(b) practical aspects of scientific industrial activity (physicists 41%, chemists 31%), e.g. workshop practice, computer programming, electronic research techniques, plant engineering and control;

(c) theoretical knowledge (physicists 14%, chemists 10%), e.g. mathematical techniques, foreign languages, logic, 'keeping up with one's field';

(d) dealing with people (physicists 12%, chemists 17%), e.g. human relations and personnel management, psychology, 'co-operation and communication with non-scientists'.

With regard to the usefulness of topics and the detailed group results catalogued in Appendix 3, certain trends are readily discernible. If a test of a meaningful trend is that all groups of an identified collection should lie on one side or other of the average percentage, that is the overall percentage for that discipline, then, for example, there is no clear distinction between all of the managers and all of the non-managers in any of the topics. The trends which are exposed on applying this test to various collections of groups are summarised in Tables 5 and 6 ('high' topics are those for which all the groups in the collection show percentages above average and 'low' topics are those for which all the groups show percentages below average). They present no conflicting features between physicists and chemists and, in several instances, the trends are identical.

Table 5. Group trends, according to usefulness of various topics, for physicists.

HIGH	GROUP COLLECTION	LOW
Costing Verbal delivery Critical path analysis	All Industrial Managers (O, P, Q, R)	Laboratory design
Above topics + Patent Law Conversational foreign language	Industrial Managers with more than 3 years in industry (P, Q, R)	Above topic + Computer technology
Laboratory design Literature searching Project planning Quality control	Non-managerial Industrial Technologists (L, M, N)	Operational research
Literature searching Laboratory design	Young physicists (E, L, M)	Conversational foreign language Costing
Laboratory design Literature searching	Non-managerial Non-industrial (E, F, G, H, J)	Patent Law

Table 6. Group trends, according to usefulness of various topics, for chemists.

HIGH	GROUP COLLECTION	LOW
Industrial law Quality control Work study	All Industrial Managers (O, P, Q, R)	Computer technology Literature searching
Above topics + Patent Law Costing	Industrial Managers with more than 3 years in industry (P, Q, R)	Above topics
Patent Law	Non-managerial Industrial Technologists (L, M, N)	Operational research Statistical analysis Industrial law Costing Critical path analysis Sociology
	Young chemists (E, L, M, O)	Costing Conversational foreign language
Literature searching Computer technology	Non-managerial Non-industrial (E, F, G, H, J)	Patent Law Quality control
Conversational foreign language	Managerial Non-industrial (A, B, C, D, I)	
Conversational foreign language	Old Chemists (A, B, C, D, H, I, N, Q, R, S)	

A more detailed inspection of the results in Appendix 3 shows that most of the topics which are 'high' for industrial managers become more useful for non-managers as they gain industrial experience. It is also found that the non-managers who are non-technologists in industry find more than average use for many topics which appear 'low' for non-managers who are technologists.

Discussion

Several factors need to be considered in debating the desirability of providing instruction at the undergraduate level in topics which have a significant level of usefulness for the industrial scientist. The topics listed in question 2 clearly fall into two groups. There are those which are immediately useful to the scientist-technologist on first entering industry, such as report writing, verbal delivery, literature searching, project planning and, perhaps to a lesser extent, laboratory design and, for the physicists in particular, statistical analysis and computer technology. The second group of subjects becomes increasingly useful as the scientist gains experience, whether he becomes a manager or not, and contains such items as costing, conversational foreign language, quality control, operational research, critical path analysis, patent law and work study. It also emerges from the analysis that the scientist who enters industry and chooses to engage in a non-technological activity will find more use for several subjects in the second group than for those concerned with experimental work in the first. Although the number of returns suggesting other useful topics was too small to provide reliable trends it is reasonable to assume that many of the management topics would fall in the second group and many of the scientific ones in the first.

Dealing first of all with subjects in the first group, the only subject where the degree of instruction approached the level of usefulness was statistical analysis for physicists and, even here, a large gap still remains. The most impressive differences between usefulness and instruction received were in verbal delivery and project planning. Even if one assumes that the instruction claimed was entirely relevant to industrial applications then, clearly, in none of the topics was there provided adequate instruction to meet the needs of a large number of industrial scientists.

At this stage, it is appropriate to establish some of the factors which determine the extent to which a high degree of usefulness justifies the inclusion of a topic in an undergraduate course for the prospective industrial scientist. In some subjects, the time factor predominates as the determining issue. Report writing and verbal delivery are skills which are developed over a long period of time. If it is felt that the acquisition of these skills cannot be left until the scientist enters industry then, clearly, current courses do not meet the need. Subjects such as computer technology, statistical analysis, literature searching and project planning may well be studied, when needed, on the job, but prior knowledge would result in a more effective approach in the first place, and expose lines of attack which would not occur to the uninitiated. If the scientist is to learn as he goes along in industry, can he or the industry afford his mistakes and hesitations during the potentially highly productive and creative part of his early scientific career?

The desirability of including such subjects in undergraduate courses is a less controversial issue than that concerning management topics. Certainly, with respect to communication, it would be hard to find any statements contradicting that of the Robbins Committee[5] that students "need constant practice and adequate training in the art of communication, both oral and written", after observing that "we are impressed by the evidence that students do little written work during the term and get too little detailed criticism of what they do submit". Concern with the desirability of educating scientists in the area of business studies and management training results in less certainty. The survey answers show that business topics and management techniques, whether in the list or suggested by respondents, will have significant usefulness for many scientists at some stage in their careers. Also shown is the fact that training in any of these areas has been on a very small scale.

It is useful to consider whether these results, which are to some extent of historical interest, can be regarded as a secure basis for future planning. We have seen, for instance, that non-managerial, non-technologists show earlier interest in these topics than their technological colleagues. Can we assume that in future they will form as small a percentage of the young scientific community as at present? Certainly, as our industries become even more technologically complex, many of the tasks presently carried out by non-scientists, in sales and marketing for example, will need to be adopted by scientists with a commercial interest, and the numbers engaged in positions attributed to those defined as non-technologist scientists will multiply. Unless the undergraduate is exposed to areas concerning these topics, the situation suggested by the sample will persist, where the scientist engaged in non-technological activities will initially embark on a technological career, being conditioned by his training, and make the change after realising his greater interest in other activities.

The educator faced with the desirability of including non-scientific topics in undergraduate science courses is not only concerned with the scope of such coverage, but also the depth required. The question asked is whether it is enough to provide an introduction to such areas to breed attitudes which are sympathetic to the aims of industry and generate an attraction for an industrial career and a management goal, or need one provide sufficient depth to enable the scientists to engage in managerial activities soon after entering industry. The answer will clearly not be the same for all extra-scientific topics. A distinction needs to be made between management of scientific activities, requiring such subjects as project planning, decision making, operational analysis and so on; intermediate management areas of concern to the non-managerial scientist such as patent law, industrial psychology, economics and costing; and business management and administration as such.

The Robbins Committee makes a division on the basis of feasibility of subject teaching. Certainly they acknowledge the desirability of introducing extra-scientific studies[6]: "There is scope for a widening of the horizons for students of science and technology. Examples of what we have in mind are studies of the economic and social problems likely to concern the students in their careers and of the social and aesthetic implications of the form of production in which they may be engaged." They go on to say[7], with reference to such subjects as "commercial law, industrial psychology, accounting, statistics and operational research", that "they are eminently suited for study at the first degree level either in combination with courses in social studies or grouped with technology";

however, "education for management as such" presents problems concerning appropriate methods of teaching, and with respect to courses "it is difficult to devise one for those who have had no experience in industry and commerce". A case is made for providing courses for students "when they have already begun to establish themselves on careers". The British Association for the Advancement of Science found[8] a similar response from "industrial witnesses and, more markedly, the education officers of the professional institutions consulted" who "were inclined to oppose the inclusion of 'management' subjects in first degree courses, if not altogether. Some were, nevertheless, in favour of providing for them by means of postgraduate courses, to be followed at an appropriate period after graduating."

A general picture of an undergraduate course for the prospective industrial scientist emerges in which more training in communication is highly desirable; the learning of planning and analytical techniques and economic factors associated with the scientist's technical activity would be valuable; the general familiarisation with the structure of industry, the sociological and economic implications of industrial activity and the study of matters relating to human relations would be desirable; but detailed considerations of business management to a level which would fit the scientist for a management position are best left to some postgraduate stage. The educator is now faced with the practical problems of providing such a course.

2. Lengthening or Abridgement of Conventional Courses?

Respondents were asked (question 4) to indicate whether they felt it was better to lengthen courses, abridge courses with regard to conventional content, or to abridge and lengthen to include such subjects as those listed in question 2. The results are given in Table 7.

Table 7. Scientists' choice between lengthening and/or abridging conventional courses to include extra subjects.

	Percentages of	
	Physicists	Chemists
Courses should be lengthened	20	15
Courses should be abridged	37	40
Courses should be lengthened and abridged	33	37
None	11	8

Trends in the individual group responses (not reported here) showed marked similarities between physicists and chemists and these were dependent on age, position and experience rather than discipline. The trends for the whole sample are shown in Table 8.

Table 8. Group trends with respect to lengthening and/or abridging courses.

Courses should be:		Lengthened	Abridged	Lengthened and abridged
PHYSICISTS	High	Non-managerial non-industrial	Non-managerial industrial	Industrial managers
	Low	young industrial, non-managerial industrial with less than 13 years in industry		
CHEMISTS	High	Non-managerial non-industrial with less than 13 years in industry	Industrial young, non-managerial industrial with less than 13 years in industry	Industrial managers with more than 3 years in industry
	Low	young industrial, non-managerial industrial with less than 13 years in industry		

It seems that there is no clear preference for either abridgement alone, or for abridgement combined with the lengthening of courses, to make way for new material, and only a minority feel that lengthening alone is to be preferred. It is interesting to consider briefly the opinions of those respondents who specified aspects of undergraduate courses which could be omitted (question 5). No answers to this question were received from about 25% of both physicists and chemists, although many of these favoured abridgement and/or lengthening of courses, whilst 5% indicated that none of the parts of undergraduate training could be omitted. The remainder of the sample produced 506 suggestions of parts for omission in physics courses and 467 in chemistry courses.

The most frequently occurring suggestions from the physics sample concerned the teaching of obsolete or out-of-date material (18%). A further 15% of the replies were critical of specialisation whilst 14% dealt with practical work. Of the remainder:

9% suggested that repetition of work could be avoided
7% referred to mathematical work
4% referred to 'subsidiary' subjects
3% were critical of purely academic topics
3% suggested that better use could be made of the vacations
3% were critical of traditional lectures as a teaching method.

The majority of other answers were concerned with specific topics of study and in decreasing order of frequency of occurrence, these included:

optics, nuclear physics, properties of matter, heat, history of science, quantum mechanics, foreign languages, electrostatics.

The most frequent comment of the chemists concerned practical work (20%). In addition, 19% of the replies were critical of specialisation whilst 17% of the suggestions dealt with factual content and 11% concerned the omission of out-of-date, classical or historical material. Of the remainder:

7% were critical of ancillary or 'subsidiary' topics
4% suggested that more time could be released by avoiding repetition
3% concerned lectures and improved teaching aids
3% commented on the length of vacations and the amount of 'free' time.

Many respondents referred to specific subjects and the frequencies of occurrence decreased as follows:

organic, individual chemical compounds (frequent reference to natural products), inorganic ("slog through the elements"), foreign languages, statistical mechanics, physical chemistry, thermodynamics, history of science.

<u>Summary</u>

It seems that there is considerable opportunity for abridgement of conventional courses. Many scientists, whether physicists or chemists, feel, for example, that much of conventional practical work could be omitted. This does not necessarily mean that they think less time should be spent in the laboratory. Later in the analysis, we shall find that some new approaches to practical work are recommended. Many were critical also of specialisation in undergraduate courses and suggested that there should be less emphasis on detail and specialised treatment of various topics, and less attention to other than basic principles and fundamentals.

A large number of physicists and a smaller, but appreciable, number of chemists suggested that time could be saved by reducing the emphasis on obsolete material and on an historical approach to each discipline. They suggested that work which is only of historical importance such as out-of-date measurements, processes and theories could be abridged. This area is fraught with difficulties in that a conflict of requirements occurs in attempting to satisfy the needs of the industrialists on the one hand and the syllabus needs of the educator on the other. These difficulties have limited the pruning of past courses to an extent, which many consider to be insufficient.

A large number of chemists were critical of the amount of factual material that needs to be learned in chemistry courses. They suggested that such effort, involving memory work which could be replaced by referring to books and which was necessary only for passing examinations could be avoided. The factual content of physics courses caused far less concern. Respondents indicated that abridgement is also possible by avoiding repetition of school work and material common to different parts of the same course, by reducing the number of formal lectures and the length of vacations, and by making more use of teaching aids including printed lecture notes.

3. Important Attitudes for an Industrial Scientist

The aim of this part of the enquiry is to establish the extent to which the scientist in industry should be concerned with those aspects of the industrial activity which are not directly involved with the scientific challenge of his task.

In question 1 scientists were asked to indicate the level of importance of various attitudes for a scientist in industry and to suggest other attitudes they consider to be important. Because of the brevity of the questions, ambiguities are present in some of the questions which would seriously limit the usefulness of the information obtained if it were intended to make a deep study of attitudes and draw rigid conclusions in attempting to characterise the industrial scientist. However, the aim here is to obtain a general guide to the desirable level of involvement of the scientist with company fortunes, as reflected in his attitudes to the selling function, management decisions, the profit motive and his own concern with budgeting and costing and his identification with company success, and the scope of the enquiry is probably sufficient for this limited aim. Answers were received from 96% of the physicists and 99% of the chemists; 44% and 43% respectively offered other attitudes they considered to be important. The level of importance of the various attitudes is set out in Table 9.

There is an indication that a larger percentage of chemists than physicists feel that these attitudes are important since, in each case, they show higher results in the 'Important' and 'Extremely Important' alternatives. Whether this is because more of the chemists in the sample were in industry compared with the physicists can be established by inspecting the group distributions of responses and the main observations which emerge from such an analysis are recorded in Table 10. Details of the various responses are listed in Appendix 4.

Table 9. Level of importance of various attitudes for scientists in industry expressed as percentages of total physics and chemistry replies.

Chemists Physicists	Extremely Important	Important	Desirable, not essential	Not Important
Identification with company success	31 25	48 46	20 25	2 4
Concern for necessity of budgeting and cost saving	27 22	52 51	20 23	2 4
Belief in profit motive	22 10	37 33	29 36	11 19
Appreciation of importance of the selling function	22 15	48 43	24 32	6 9
Acceptance of management decisions	17 14	50 49	26 25	6 10

Other attitudes which respondents considered to be important for a scientist in industry were suggested by 324 physicists and 284 chemists. Although the analysis of these replies presents great difficulties in interpretation, answers can be divided roughly into three main groups: those which concern the attitudes of the scientist with respect to his scientific task, those which concern his attitudes with respect to the organisation and his place in it and, finally, his attitudes with respect to his own, not necessarily scientific, abilities and his relationships with other people. There follows an outline of each category together with an indication of the population of replies in each sub-division (chemists, physicists).

A. Attitudes with respect to the scientific task were subdivided as follows:

(27, 27) Real interest in, and enthusiasm for the job. Getting satisfaction and fun from the job.

(23, 27) Belief in the importance of the work undertaken. Clear idea and acceptance of the objective of one's own work.

(19, 24) Technical and practical competence. Common sense and good judgement. Scientific insight.

(18, 16) Imagination, curiosity and originality. Desire to be creative and make new discoveries.

(17, 18) Tenacity, self-discipline, hard work, perseverance and a sense of urgency.

(13, 27) Independence of attitude and thought. Individualism. Courage of convictions. Challenge of management decisions. Constructive criticism.

(13, 7) Keeping up to date. Willingness to learn.

(6, 10) Awareness of the time factor and the need for programme planning.

(6, 4) Self-confidence and faith in own ability.

(3, 5) Conscientiousness and thoroughness.

(2, 7) Professional recognition and scientific standing outside firm. Importance of publications and meeting other scientists.

(2, 6) Awareness of the boundary between practical and academic work. Ability to translate research results into commercial production.

B. Attitudes which respondents thought the industrial scientist should adopt with respect to his organisation role were subdivided in the following manner:

(23, 15) Awareness of, and interest in organisational problems. Interest in functions other than own, and liaison with non-technical colleagues in other sections. Appreciation of the work of non-scientists. Awareness of the structure of the company and one's own place in it.

(16, 32) Belief in company objectives, philosophy or policy. Recognition that the company's survival depends on profit and decisions are made accordingly and that industrial science is a commercial concept aimed at making a profit. Appreciation of market research, economic role of own industry and place of own project with respect to economic usefulness.

(12, 10) Understanding of, and participation in management decisions. Interest in business management and learning modern management techniques.

(6, 7) Loyalty to the company and confidence in management. Willingness to concede overall direction to management.

(4, 4) Freedom to pursue own research ideas. Independence in research and pursuit of pure research where possible.

(3, 5) Concern with remuneration and prospects and that they should be on a par with other company staff.

(2, 3) Appreciation from, and recognition of contribution by superiors.

Table 10. (A) Chemistry group trends relating to the importance of various attitudes for a scientist in industry.

Attitude	Location of Group Maxima	Group trends with respect to importance	
		High	Low
Identification with Company success	All groups in 'important' or 'extremely important'	Managerial groups with industrial experience	
Concern for the necessity of budgeting and cost saving	All groups in 'important'	Tendency for all managerial groups and industrial non-technologists	
Belief in profit motive	13 groups in 'important' plus 6 non-industry groups in 'desirable but not essential'	Industrial groups	Non-industrial groups, especially managerial ones
Appreciation of importance of the selling function	All in 'important' except 1 non-industrial in 'desirable but not essential'	Industrial non-technologists plus a tendency for all industrial groups	Non-industrial groups
Acceptance of management decisions	14 groups in 'important' or 'extremely important' plus 5 groups elsewhere	No obvious trends	

Table 10. (B) Physics group trends relating to the importance of various attitudes for a scientist in industry.

Attitude	Location of Group Maxima	Group trends with respect to importance	
		High	Low
Identification with Company success	18 groups in 'important'or 'extremely important' plus 1 non-industrial in 'desirable but not essential'	Industrial managerial groups	
Concern for the necessity of budgeting and cost saving	All groups in 'important' or 'extremely important'	Industrial non-technologists	
Belief in profit motive	5 groups in 'important', 10 in 'desirable but not essential' and 4 non-industrial in 'not important'	Industrial groups	Non-industrial groups, especially managerial ones
Appreciation of importance of the selling function	15 groups in 'important' and 4 in 'desirable but not essential'	Industrial non-technologists	
Acceptance of management decisions	18 groups in 'important' and 1 in 'extremely important'	No obvious trends	

(0, 3) Concern with patriotism and national prestige.

C. The last group of recommended attitudes concerns those which relate to personal characteristics as they affect other people and determine individual behaviour. They are subdivided as follows:

(43, 45) Ability to work in a group. Concern for, and ability to get on with fellow men. Good relations with subordinates. Willingness to co-operate and belief in collaboration.

(19, 13) Open mindedness, flexible attitude, broad outlook and adaptability. Willingness to compromise.

(16, 20) Honesty. Scientific and personal integrity.

(11, 13) Ability to communicate with, and sell ideas to scientists, management and non-scientists.

(7, 11) Initiative, self-motivation, drive and 'get up and go'.

(7, 6) Ability to organise and handle men. Leadership and man management.

(7, 3) Sense of responsibility.

(5, 12) Sociological awareness and a concern with the impact of science on society. A desire to do useful work for the community and a concern with moral responsibilities.

(5, 8) Ambition. Concern with own success and career development.

(4, 1) Prudent modesty and a proper humility.

(3, 0) Good manners, tact and discretion.

(2, 4) Positive thinking and optimism.

(2, 2) Curiosity. A conscious search for general knowledge.

(0, 5) Respect for, and an understanding of, other abilities, e.g. artistic and practical.

Summary

There is little doubt that the vast majority of scientists consider that it is desirable for a scientist in industry to concern himself with the commercial aspects and the organisational problems of his firm's activities; many of these think it is important and an appreciable number that it is extremely important that he should do so.

Industrialists, as a whole, tend to emphasise the importance of these attitudes compared with scientists who are not in industry. There is a tendency for physicists in industry to attach less importance to a belief in the profit motive and an appreciation of the selling function than do industrial chemists, so that the differences between chemists and physicists shown in Table 9 are, in these cases, due to a feeling on the part of the physicists as a whole that the concern of the industrial scientist with these areas is of less importance. The feelings of industrial physicists and chemists about the importance of the other three attitudes are very much the same.

Identification with company success and a concern for the necessity of budgeting and cost saving are attitudes which the majority of scientists in physics and chemistry consider to be highly desirable for the scientist in industry and there is a noticeable trend for all groups of managerial chemists who have had experience in industry, and industrial managerial groups of physicists to emphasise this importance. Although the majority of scientists consider the acceptance of management decisions to be highly desirable, there are fluctuations in the group feelings amongst chemists which do not appear to follow a particular pattern. The non-technologists in industry particularly emphasise the importance of those attitudes concerned with the economic aspects of the industrial activity.

The only other variable which appears to determine a contrast in views is the location of the scientists in an industrial or non-industrial organisation. There is a clear division between the level of importance attached to a belief in the profit motive by scientists in industry, whether physicists or chemists, and non-industrial scientists. If the 'important' and 'extremely important' are added, then in the chemistry results all of the industrial groups score higher than the non-industrial ones for 'highly desirable' and, although the physicists tend to attach less emphasis to a belief in the profit motive, a similar split in attitudes between industrialists and non-industrialists occurs. A similar disparity occurs in the chemists' views on the appreciation of the importance of the selling function. A further trend occurs in the results for non-industrialists in that managerial non-industrialists suggest even less emphasis than non-managerial, non-industrialists.

From the educator's point of view, it is important to observe that nowhere in this part of the analysis does age, on its own, appear to influence the views of the scientists. In the profit motive question, for example, the young industrialists attach more importance to this attitude than do the young non-industrialists, the important variable being the location of the scientists.

Two important conclusions follow from these observations. In the first place there is obviously a clash between the views of non-industrialists, who include the educators, and those of industrialists concerning the desirable attitudes of an industrial scientist with respect to the profit motive and, to some extent, the importance of the selling function; the clash being especially evident between the managerial non-industrialists, who include heads of science departments in educational establishments, and industrialists. Secondly, the absence of any indication that increasing age, on its own, tends to change views, emphasises the importance of encouraging in the potential industrial scientist, before he embarks on an industrial career, those attitudes thought to be desirable in an industrial scientist.

Scientists suggested many other attitudes which they considered to be important for an industrial scientist, and these were generally common to both physicists and chemists. Eighty-eight (about 15%) of those who offered suggestions emphasised the importance of team work and the ability to work in a group. Other attitudes considered to be important by a significant number of scientists included: a real interest in, and enthusiasm for the job (54); belief in the importance of the work undertaken (50); belief in company objectives and appreciation of the economic implications of industry and industrial science (48); technical and practical competence (43); and several others detailed above.

The implications of these desirable attitudes with respect to undergraduate education are not always clear. In some cases the relevance is obvious - for example with technical and practical competence. In others, a desirable level of impact on education is debatable - for example, the appreciation of the economic implications of industry, although a case has been stated for including such matters in undergraduate courses not only for training purposes but to facilitate career guidance. Others involve a consideration of the nature of the maturing process. For example, how and when does a scientist acquire an ability to work in a group; does this come naturally during the course of industrial activity, or need the seed be sown earlier? One strongly suspects that much can, and should, be done in undergraduate courses to cultivate desirable attitudes with respect to team activity which are emphasised as being of importance both in the answers to question 1 and to question 7.

4. Desirable Attributes for an Industrial Scientist

In answering question 7 scientists were asked to indicate which of a list of fourteen attributes they considered to be particularly desirable for an industrial scientist occupying various positions, namely, plant manager, research group leader, technical service manager and marketing or planning manager. This question was designed to help the student who is seeking career guidance and also to help the educator to ensure that, as far as possible, important attributes are exercised in undergraduate courses so that he, as well as the student, can assess performance in important areas, and provide practice for the development of desirable accomplishments in the student.

Some of the scientists chose not to answer for one or more of the positions indicated, claiming that they had insufficient knowledge of the work involved in a particular job. A larger percentage of physicists than chemists declined to answer for the positions other than research group leader and, of the physicists, the non-industrialists were clearly less inclined to answer than the industrial scientists. There was no such obvious trend in the chemistry replies. The overall percentages of physicists and chemists respectively who did not answer for the various positions were: plant manager - 11% and 6%; research group leader - 3% and 3%; technical service manager - 12% and 9%; and marketing or planning manager - 15% and 10%. Although the percentages are different for physicists and chemists, they show the same order of familiarity with the various positions for both groups.

The results are considered as percentages of the total number who answered for a particular position and these have been used to produce the information given in Table 11 which shows the relative importance of the various attributes for scientists occupying the four positions named in the questionnaire. There was good agreement between the two disciplines and no marked trends when identifiable collections of groups were considered in the manner employed in dealing with other questions.

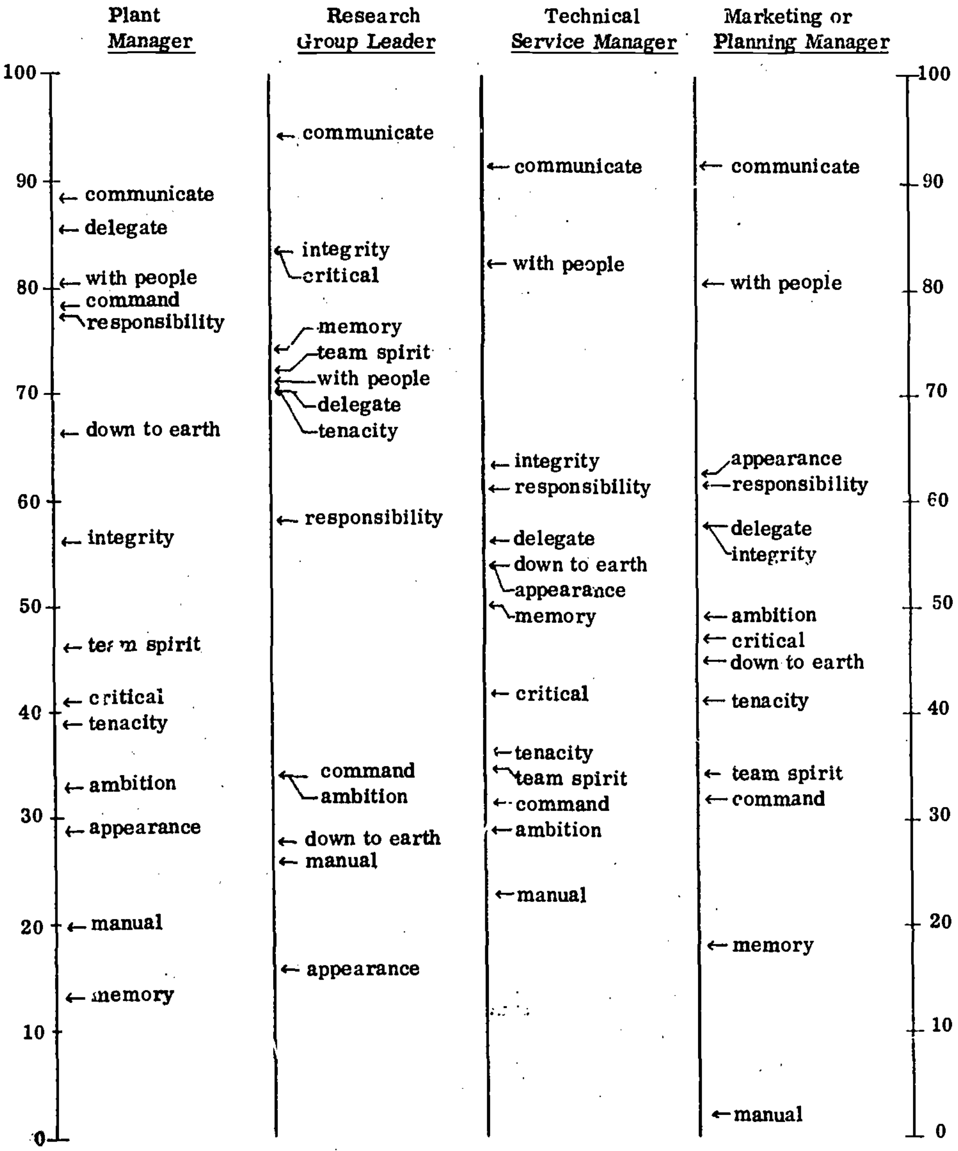
Two abilities are considered by the great majority of scientists to be particularly desirable in all four managers. More scientists in each case support the desirability of the ability to communicate than any of the other attributes listed; and the ability to get on with people is considered to be particularly desirable for each of the managers, by a large percentage of all scientists. This confirms the emphasis placed on the desirability of these capabilities in the industrial scientist in other parts of the analysis. Furthermore, more than 50% of all of the scientists consider it highly desirable that scientists occupying all four positions should desire to accept responsibility and exhibit professional integrity. It is noteworthy that 80% of the scientists feel that professional integrity and a critical attitude are particularly desirable for the research man compared with about 60% and 40% respectively for the other positions.

Scientists were also given an opportunity to suggest other attributes which they thought would be particularly desirable in scientists occupying the positions shown. Only 22% of the physicists and 22% of the chemists took advantage of this opportunity and the 183 physicists and 146 chemists who offered suggestions distributed them amongst the positions as follows: plant manager (physicists 149, chemists 128); research group leader (194, 171); technical service manager (120, 118); and marketing or planning manager (133, 118). Once again, the answers could be categorised according to their particular relevance to the manager's concern with his technical ability, his dealings with people and his personal characteristics, or his concern with company affairs. Nearly all of the categories are common to both physics and chemistry replies and the numbers shown below correspond to the total number of respondents who made the suggestion, in the order, plant manager, research group leader, technical service manager and marketing or planning manager.

The attributes concerned with the technical activities of the manager are subdivided as follows:

(36,51,31,35)	Non-dogmatic, logical, analytical approach.
(14,44,12,24)	Original, flexible mind. Inventiveness. Creative ability and ingenuity.
(20,31,16,18)	Enquiring mind. Ability to accept new ideas. Enthusiasm for keeping up to date with subject.
(22,24,17,20)	Sense of urgency. Drive. Ability for hard work. Ability to concentrate.
(10,19,10, 7)	Academic ability. Scientific insight. Sound fundamental knowledge of subject.

Table 11. Scientists' views on the relative importance of various attributes for scientists occupying different positions.



Percentage responses of whole sample

Description of attributes:

ability to communicate

down to earth attitude

ability to get on with people

ability to delegate authority

tenacity

personal appearance

critical attitude

power of command

ambition

desire to accept responsibility

team spirit

manual dexterity

professional integrity

memory for scientific information

(8, 9, 9, 4)	Technical ability and practical experience. Wide technical knowledge.
(9,10, 7, 5)	Versatility. Ability in many disciplines. Ability to think in broad terms.
(5, 6, 4, 5)	Awareness of research elsewhere and current developments.
(1, 3, 2, 1)	Memory for general information and knowledge of information sources.
(1, 3, 1, 2)	Mathematical ability.

Several of these suggestions and those that follow are similar to those obtained in answer to question 1, where the concern was more with the desirable attitudes of the industrial scientist with respect to his commercial role. However, respondents were selective in locating their answers so that suggestions were repeated on the same questionnaire only in a negligible number of cases. Where suggestions are repeated in the results, th, s should be regarded as an emphasis on the desirability of the suggestion and not as a repetition of statistics.

Because most suggestions with respect to the business involvement of the industrial scientist were given in answer to question 1, there were few replies concerned with this area in answer to question 7 and these were as follows:

(9, 9, 9, 9)	Participation in, and concern with, company activities and structure.
(7, 5, 8, 8)	Knowledge of costs and economics. Commercial acumen.

Many replies concerned the relationship of the manager with other members of his organisation, and his personal qualities which affect the performance of his management task. The suggestions received were:

(29,34,22,20)	Leadership. Ability to command respect and to use people effectively. Ability to inspire others and to organise and administrate.
(18,18,12,11)	Understanding of human relations. Sensitivity to other peoples' feelings and difficulties. Patience and tolerance and tact.
(12,17,10,10)	Concern with and interest in welfare and careers of subordinates.
(13,13,13,11)	Honesty. Personal integrity.
(11, 7, 4, 4)	Calmness and confidence. Unflappability. Ability to work under pressure. Even temperament.
(9,13,12,13)	Enjoyment of life. Sense of humour. Positive, optimistic and enthusiastic outlook.
(7, 7, 3, 6)	Ability to make decisions.

(6, 6, 5, 5)	Ability to listen. Receptive of new ideas.
(3,10, 5, 6)	Ability to sell an idea and to speak correctly. Persuasiveness.
(6, 4, 5, 4)	Informality. Approachability.
(3, 2, 3, 3)	Pleasant personality. Personality.

Conclusions about the relative importance of the various attributes are particularly unreliable in this case, because of the small response and the duplication of information already recorded elsewhere. The main contribution of these spontaneous suggestions is in emphasising desirable features of the industrial scientist which may have already emerged and in amplifying and defining more precisely the implications of various attributes which are briefly described in the questionnaire.

5. Scientists' Views on Course Design

Up to this point in the survey scientists had an opportunity to identify shortcomings in conventional courses and to describe the attitudes and activities of the industrial scientist. In answering question 8 they were given an opportunity to suggest ways in which courses could be designed to improve the preparation of students in science for industry.

Answers to question 8 were received from 551 (75%) of the physicists and from 480 (73%) of the chemists and about 70 of the forms had accompanying letters in which the suggestions were extended and amplified. Many of the respondents suggested more than one way of improving course design and, after breaking down the answers, the number of replies received from physicists and chemists was 888 and 772 respectively. That so many professional scientists are interested in making a positive contribution to course design is very gratifying; that so many should feel the need for change is added encouragement for the design of a course directed more towards the needs of industry.

The physics and chemistry replies were categorised separately, and it was found that nearly all of the categories were common to both samples. There follows a description of the various categories together with an indication of the number of suggestions received in each case, the first and second numbers applying to the physics and chemistry response respectively. The categories are listed in order of magnitude of populations, but it should again be emphasised that comparisons of importance should be made with care, not only because of variations in range of category and other factors mentioned earlier, but because, in some cases, the respondent may choose not to repeat views expressed elsewhere on the questionnaire.

(137, 96) of the suggestions express the desirability of getting the students into industry for a period of their undergraduate training. The suggestions include thin sandwich and thick sandwich courses and, while some propose compulsory industrial experience during the vacations, the general view is that courses should be extended to provide for industrial experience. Some respondents suggest that this experience should embrace not only laboratory work, but also experience in production, planning and sales departments. That such industrial experience should be carefully planned is emphasised: "It is essential that the student should not be used as an odd job boy, but made to assist in a definite project. He should feel wanted." Not only should it encourage students to enter industry, but industrial experience will help them with respect to career guidance: "Most students could work in three different types of industry while at college and when they graduated they would be in a much better position to judge industry and make decisions as to where they would like to work and in what fields."

(107, 63) of the suggestions concern the practical work in a course. Many of these propose project work both by individuals and teams in place of many of the set experiments involved in conventional courses. There is a plea for the use of modern instrumental techniques in experimental work and some respondents suggest that projects should be concerned with real industrial problems or should involve considerations which are important in industry, such as costing, planning and construction: "More use should be made of practical projects which are related to the type of work the scientist will do in industry. He should write these up in a form designed to inform others rather than just some aide-memoire for himself."

(96, 88) of the respondents suggest that more emphasis should be placed on the applications of science to industry. They propose that students should be made more aware of the technological usefulness of science by exposing them to contemporary industrial practices and problems and by taking the emphasis off the 'academic' and placing it on the 'applied' sciences.

(24, 20) of the replies make more extreme but similar pleas to those outlined in the previous category, in that they are concerned that students should be convinced that industrial science is not a second grade activity: "Avoid creating a 'poor relationship' attitude of industrial science compared with academic research". "Emphasise that neither profit nor industry are dirty words." "Destroy the superior attitude of the academic towards the profit motive and technologists." "Eliminate the idea that exists in some universities that industry is unworthy." This category is included out of order in terms of population magnitude since it is clearly associated with the previous one, but all of the replies in this case emphasise the desirability of changing the unattractive image of industrial activity that academics are charged with presenting.

(75, 89) of the respondents propose the desirability of greater contact between academics and industrialists, a greater involvement of industrialists in academic activities and of academics in industry. More specifically, many suggest that industrialists should provide lectures and tutorials for undergraduates. Academics should engage in applied research or work on projects jointly with industry, and should be encouraged to act as consultants to industry and spend some time in industry each year. Industrialists should provide real problems for student project work and for postgraduate study and should participate in course design.

(76, 86) of the recommendations concern the inclusion of some of the subjects listed in question 2. Several replies propose that such topics should not be taught at a specialist level, "but sufficiently well to make one conversant with specialists in these fields".

(67, 58) respondents are concerned that emphasis should be placed on basic theory and fundamentals rather than on complex theory and detailed treatments. There is some suggestion that a wealth of detail obscures fundamentals: "a thorough comprehension of basic facts, principles and laws and of scientific method should be imparted, care being taken that they are not obscured by a wealth of detailed description of past experiments". Several respondents suggest that specialisation should be reserved for postgraduate attention.

(59, 46) of the suggestions advise the inclusion of lectures on the structure and aims of industry, the role of the industrial scientist, industrial relations and the relative functions of different industrial departments. Not only is this considered important to equip the scientist for a more useful industrial role, but it should assist him with respect to career flexibility: "a very significant portion of trained scientists ends up in marketing, administration, etc.; and on their advent into industry they are embarrassingly naive". Career guidance is considered wanting in conventional courses: "too many students know too little of the types of opportunity which are available", and such lectures are expected to help meet the need.

(44, 47) comments concern the desirability of lectures in undergraduate courses on management techniques, business studies and the economic implications of industrial activity. That such training would be necessary preparation for career development is often expressed: "include short courses on management as most good scientists become managers or administrators sooner or later in industry and they are not trained to do the job".

(34, 35) respondents recommended special training in report writing and public speaking. The development of the student's ability to communicate both with scientists and non-scientists should be encouraged. That the ability to communicate effectively is essential to the industrial scientist has been especially emphasised in answers to other questions in the enquiry and only a few respondents felt it necessary to explain this need here: "scientific knowledge is barren unless it can be conveyed effectively to all the people who need to make use of it". Many of the answers emphasised the shortcomings of most graduate scientists in this respect: "one of the greatest failures is in effective written and verbal communications. Instruction, or at least guidance should be given in both."

(29, 25) of the scientists recommended that subjects specifically for potential industrial scientists, such as the topics listed in question 2, are best left to postgraduate courses, either full-time, leading to a qualification, or part-time short courses for scientists in industry. All of these replies acknowledge that training in extra subjects is desirable and it is generally felt that such training is best left until the scientist has had some experience in industry or, in some cases, as a substitute for conventional postgraduate courses.

(12, 15) answers proposed more mathematical training. The replies here particularly expressed a need for more training in statistical analysis and its application in planning experiments and establishing the meaning of results.

(18, 13) respondents suggest that teachers of undergraduate courses should have previous experience in industry, ranging from three to ten years. This is expected to change the pattern of courses and to improve the image of industry. There is the occasional personal testimony to the value of industrial experience in education: "as a science teacher with a background of ten years' industrial experience, I believe that the confidence of knowing how to handle apparatus, perform experiments, and give instructions to stewards, as well as the ability to quote examples from experience, is of far more value than all the educational theory I have since studied".

(10, 12) respondents feel that students should be separated into two streams, one doing an industrially biased course and the other pursuing a more academic course. There is also some suggestion that the industrial course should be further subdivided in the later stages according to the type of job the student wants to do in industry. The main purpose, however, would be to provide a more suitable course for the industrialist as opposed to the intending pure research man: "except for pure research in a wealthy research establishment, a full science degree training is wasted on an industrial career. There should be a separate industrial career degree for those interested in joining a firm."

The remaining suggestions are mainly distributed as follows:

(10, 8) Disregard the particular needs of industry in undergraduate courses; concentrate on a 'good grounding' in the discipline concerned;

(11, 5) Formal lectures should be partially replaced by more tutorials, seminars, etc.; (9, 7) modern teaching techniques such as television and films should be more widely used;

(7, 4) Make advanced or specialised topics optional;

(8, 8) Real problem is the "education of industry for scientists";

(6, 9) Psychology, human relations and the humanities; (5, 8) foreign languages; (6, 3) familiarisation with other disciplines.

CONCLUDING NOTE

In this investigation, the traditional undergraduate course had been used as a yardstick and the designers of such courses may well claim that their intention has not been to attend to the particular needs of industry; but there is clear evidence that a large body of professional scientists feel that the graduates of such courses are inadequately prepared for a career in industry.

It has been shown that a course for the student of science which meets the traditional aim of providing a good scientific education and includes material of importance for preparing a student for industry can be achieved by a pruning of conventional material to a degree which would be agreeable to most scientists or, alternatively, by a lengthening of courses which the majority of scientists would find acceptable.

The overall aim of such a course has been made clear. The component aims, not necessarily in the order of importance, are seen as attending to the following factors:

To provide a sound, basic education in the special discipline.

To emphasise the nature of industrial technology and the application of science in industry.

To develop speaking and writing abilities in the student.

To acquaint the student with the aims, structure, organisational roles, economics and practices of industry.

To provide career guidance.

To encourage group participation and team activities, initiative, creativity and organising ability.

To develop a fruitful approach in the student to experimental work.

To provide courses in mathematics and a subsidiary science subject to equip the specialist for a useful scientific career.

To provide, at the end of the course, a realistic assessment of the student's abilities with reference to his suitability for an industrial role.

The success of a particular course in achieving these aims will depend not only on the attitudes and abilities of participating teaching staff in the various educational establishments, but also on the co-operation and enthusiasm of scientists in industry. The responsibility for the provision of well-educated scientists who are adequately prepared to contribute to the activities of industry should, in the writer's opinion, be shared by educators and industrialists. It is only in this co-operative manner that a realistic solution to the problem of the education of scientists for industry can be reached.

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5. Higher Education. Report of the Committee under the Chairmanship of Lord Robbins, HMSO, October 1963, p. 188.

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APPENDICES

1. The Questionnaire

Name (optional) ____

Profession, e.g. Physicist, Chemist ____

Qualifications, e.g. BSc, PhD ____

How obtained, e.g. University, Technical College ____

Years in industry ____

Age (optional) ____

Present position ____

In each section please tick ✓ what you consider to be the appropriate box.

1. Please indicate what you consider to be the level of importance of the following attitudes for a scientist in industry.

	Extremely important	Important	Desirable not essential	Not Important
Identification with company success				
Concern for necessity of budgeting and cost saving				
Belief in profit motive				
Appreciation of importance of the selling function				
Acceptance of management decisions				
Others				

2. Which of the following techniques or subjects do you feel to be useful in the light of your industrial or other experience?

(1) Computer technology	☐	(10) Report writing	☐
(2) Statistical analysis	☐	(11) Verbal delivery	☐
(3) Laboratory design	☐	(12) Conversational foreign language	☐
(4) Information theory	☐	(13) Literature searching	☐
(5) Patent law	☐	(14) Critical path analysis	☐
(6) Sociology	☐	(15) Project planning	☐
(7) Industrial law	☐	(16) Operational research	☐
(8) Costing	☐	(17) Quality control	☐
(9) Stock market	☐	(18) Work study	☐

Any others: (19) ☐ (20) ☐

3. In which of the above did you receive instruction during the period of academic training?

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4. To include such subjects, do you think that undergraduate courses should be (a) lengthened ☐ , (b) abridged with regard to conventional content ☐ , or (c) a combination of (a) and (b) ☐ ?

5. Which parts of undergraduate training could be omitted to make way for new topics?

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6. Would you be interested in attending ☐ , contributing to ☐ a conference on the education of scientists for industry?

7. Which of the following do you think are particularly desirable in scientists occupying the positions indicated?

	Plant manager	Research group leader	Technical service manager	Marketing or planning manager
Ability to communicate				
Down to earth attitude				
Ability to get on with people				
Ability to delegate authority				
Tenacity				
Personal appearance				
Critical attitude				
Power of command				
Ambition				

7. (continued)

	Plant manager	Research group leader	Technical service manager	Marketing or planning manager
Desire to accept responsibility				
Team spirit				
Manual dexterity				
Professional integrity				
Memory for scientific information				
Others				
....				

8. What do you think can be done in course design to improve the preparation of students in science for industry? (Please use a separate sheet of paper if necessary to enlarge on this or any other answer.)

2. Classification of Scientists according to Management Responsibility and Technological Involvement

	MANAGER	NON-MANAGER
INDUSTRIAL TECHNOLOGIST	Chief Physicist, Chemist Technical Director Section Leader Director of Research Deputy Director of Research Plant Manager Deputy Group Leader Laboratory Manager Technical Executive Works Manager Quality Control Manager Applications Manager Chief Instrument Engineer Production Section Manager Assistant Plant Manager Principal Engineer Principal Development Chemist Group Leader Deputy Chief Physicist, Chemist	Physicist, Chemist Technical Officer Assistant & Experimental Officer Senior Physicist, Chemist Scientific Officer Plant Chemist Research Chemist, Physicist Development Officer Project Leader Computer Programmer Works Chemist Plant Control Chemist Deputy Section Leader Quality Control Scientist Technical Planner Manufacturing Engineer Technical Liaison Scientist Research Assistant Production Chemist
INDUSTRIAL NON-TECHNOLOGIST	Company Chairman Management Consultant Managing Director Magazine Editor Marketing Manager Personnel Manager General Manager Head of Information Department Distribution Manager Development Executive Technical Sales Manager Manufacturing Director Manager O.R. Department Head of Planning Company Director Sales Manager Assistant General Manager Group Education & Training Officer Chief Executive Officer	Technical Sales Representative Training Officer Market Analyst Technical Writer O & M Officer Marketing Officer Information Officer Profitability Investigator Patent Agent Work Study (no rank given) Operations Planning Analyst Education Officer Planning Department (no rank given)

	MANAGER	NON-MANAGER
NON-INDUSTRIAL	Professor Divisional Head Director, Research Establishment Museum Curator County Analyst Chief Radiochemist Principal Scientific Officer SPSO Head of Department (Tech. Coll.) Assistant Director Principal Hospital Biochemist Head of Health Physics Head of Safety Group Technical Executive Her Majesty's Inspector	Scientific Officer Senior Lecturer Principal Lecturer Senior Science Master Patent Examiner Research Fellow Hospital Physicist Author Spectroscopist Senior Biochemist. NHS Assistant Regional Officer Reader Associate Professor Assistant Professor Senior Scientific Officer

3. Scientists who feel various topics to be useful, expressed as percentages of total

GROUP	Report writing	Verbal delivery	Statistical analysis	Project planning	Computer technology	Literature searching	Costing	Laboratory design	Conversational foreign lang.
A	78	56	78	100	44	56	44	44	44
	93	100	87	80	53	73	67	47	40
B	100	100	50	0	50	50	50	25	75
	89	89	78	56	78	56	56	56	33
C	100	100	67	83	50	67	67	33	50
	93	71	71	57	57	57	29	29	50
D	100	80	80	60	40	100	60	20	40
	100	87	67	67	73	53	47	33	60
E	89	78	74	70	63	78	30	48	33
	85	76	63	61	80	65	24	46	30
F	100	75	56	50	50	88	44	38	38
	90	68	73	73	83	78	23	48	23
G	91	65	70	52	43	70	61	52	30
	86	66	69	62	60	62	24	47	31
H	82	64	64	55	45	91	73	55	45
	100	80	90	50	50	100	70	70	40
I	100	88	75	88	38	75	38	63	63
	100	71	76	76	81	57	14	48	33
J	100	75	83	50	50	83	50	42	17
	95	74	84	58	79	63	26	42	37
K	84	63	53	53	17	95	68	11	53
	92	75	50	50	42	42	58	17	25
L	85	85	50	62	41	79	47	26	26
	90	72	72	77	64	68	38	42	22
M	92	73	61	67	45	75	55	42	33
	98	82	67	71	66	71	38	40	30
N	92	78	59	62	35	68	57	55	47
	100	83	78	72	59	63	48	48	35
O	100	83	67	67	33	50	50	17	17
	100	100	33	100	100	100	67	33	33
P	91	76	71	76	34	66	71	34	34
	91	80	65	63	50	67	59	33	43
Q	97	80	76	61	29	61	74	46	39
	95	81	75	61	59	47	57	37	44
R	96	84	65	65	36	60	80	24	45
	88	79	74	69	57	40	74	17	48
S	100	63	75	63	50	56	75	25	50
	96	76	53	67	63	57	45	37	41

group membership, for physicists and chemists.

Chemists
Physicists

Operational research	Critical path analysis	Quality control	Patent law	Work study	Information theory	Sociology	Industrial law	Stock market	GROUP
22	33	44	22	11	22	11	0	11	A
40	20	33	27	20	27	13	27	13	
25	0	0	50	0	0	25	0	0	B
56	33	56	33	44	22	22	22	22	
17	33	17	33	17	0	0	0	0	C
50	21	36	21	21	7	21	0	0	
40	40	60	40	40	40	0	20	0	D
60	13	33	33	13	13	20	13	7	
37	33	33	22	30	26	19	22	11	E
31	23	14	10	23	18	15	11	1	
25	19	44	38	13	13	19	19	6	F
28	35	18	13	15	23	15	10	8	
26	22	48	35	26	22	26	35	13	G
26	19	26	22	12	14	14	9	0	
36	27	36	36	27	9	9	27	0	H
20	20	70	20	60	30	20	0	0	
63	38	25	13	50	0	0	38	0	I
29	14	29	14	24	0	5	5	5	
50	50	42	33	50	17	33	17	0	J
21	37	5	11	5	16	11	0	0	
37	32	42	42	11	53	21	37	5	K
50	17	8	25	17	8	33	17	0	
26	18	21	47	15	24	8	21	0	L
30	30	35	16	22	16	17	12	3	
21	30	42	42	30	13	13	20	5	M
22	27	33	26	16	19	12	8	2	
24	31	46	50	30	15	11	15	5	N
26	37	35	26	13	13	13	9	0	
0	33	67	17	33	0	0	83	0	O
33	33	33	0	0	33	0	0	0	
31	43	50	43	33	14	10	24	2	P
20	39	26	33	11	22	11	7	2	
27	29	64	43	32	18	14	25	4	Q
33	35	40	37	19	14	18	6	1	
36	31	60	40	35	18	13	33	11	R
52	38	36	29	31	17	17	14	5	
38	31	38	6	19	6	6	25	0	S
24	55	24	22	22	22	12	4	6	

4. Level of importance of various attitudes expressed as percentages of total number of

GROUP	Company Success					Budgeting, Cost Saving					Profit	
	Extremely important	Important	Desirable not essential	Not important		Extremely important	Important	Desirable not essential	Not important		Extremely important	Important
A	11	67	22	0		11	78	11	0		0	11
	33	40	20	7		13	47	40	0		13	47
B	0	100	0	0		0	100	0	0		0	25
	50	25	25	0		0	75	13	13		0	25
C	33	50	17	0		17	67	17	0		0	17
	23	46	23	8		8	38	23	23		8	8
D	40	40	20	0		20	40	40	0		20	20
	29	36	36	0		21	43	36	0		7	21
E	26	41	26	0		22	41	41	0		4	44
	23	46	26	3		15	56	26	3		2	34
F	25	5[illegible]	19	0		6	50	38	6		13	38
	18	51	28	3		21	46	23	10		8	21
G	18	59	23	0		27	41	32	0		9	41
	23	32	41	4		20	50	23	5		8	30
H	9	73	18	0		18	55	27	0		0	36
	20	60	20	0		10	80	10	0		0	30
I	25	50	13	13		38	50	0	13		13	13
	25	65	10	0		25	40	35	0		0	25
J	8	50	42	0		17	67	8	8		8	42
	11	63	21	5		16	42	32	5		0	26
K	42	32	26	0		32	53	11	0		16	47
	42	25	25	17		50	42	8	0		8	42
L	38	38	24	3		26	38	32	6		26	32
	17	45	30	7		20	49	25	4		13	30
M	24	43	29	6		25	47	23	4		29	38
	27	43	26	3		20	52	23	5		8	33
N	35	47	15	1		24	56	19	3		19	36
	16	50	27	5		25	50	25	2		7	34
O	17	67	17	0		17	67	17	0		33	50
	33	67	0	0		33	33	33	0		33	33
P	44	42	14	0		28	51	21	2		32	37
	26	54	15	4		28	43	22	4		15	26
Q	34	49	16	1		28	54	16	1		23	36
	37	47	15	1		29	52	19	2		22	38
R	37	48	15	2		44	44	11	2		35	43
	37	44	17	2		24	66	10	0		12	51
S	25	50	25	0		19	75	6	0		13	44
	10	48	37	4		17	52	27	6		8	42

group replies received for physicists and chemists

Chemists
Physicists

Motive			Selling Function					Management Decisions				
Desirable not essential	Not important		Extremely important	Important	Desirable not essential	Not important		Extremely important	Important	Desirable not essential	Not important	GROUP
56	33		11	67	11	11		11	22	22	44	A
20	20		27	47	20	7		13	60	13	13	
75	0		25	25	25	25		25	25	50	0	B
63	13		0	63	38	0		13	63	13	13	
67	17		0	50	50	0		33	50	17	0	C
31	54		8	46	31	15		8	46	15	23	
60	0		20	40	20	20		20	20	60	0	D
29	43		14	36	43	14		29	43	29	0	
30	19		7	56	26	7		22	44	26	4	E
36	26		11	36	33	11		8	48	34	8	
25	25		13	25	44	19		19	50	13	19	F
33	38		10	49	31	10		10	44	28	18	
32	14		27	50	23	0		5	50	41	5	G
25	34		21	52	18	7		14	54	20	11	
55	9		18	45	27	9		9	64	18	9	H
40	30		0	70	30	0		30	30	20	20	
50	25		0	50	13	33		13	50	13	13	I
65	10		5	45	40	[illegible]		15	40	40	0	
42	17		25	50	17	8		8	67	17	8	J
37	32		5	42	42	11		16	47	21	16	
26	5		37	37	21	5		37	32	21	11	K
42	8		25	58	17	0		8	50	25	17	
32	6		29	44	18	6		12	68	12	3	L
41	15		17	42	29	9		13	42	38	7	
24	10		22	41	32	6		12	38	40	6	M
41	15		19	31	41	9		10	50	20	13	
32	10		21	49	25	6		11	56	25	8	N
41	18		5	45	39	11		14	50	23	5	
17	0		17	[illegible]	17	0		50	17	33	0	O
33	0		33	33	33	0		67	33	0	0	
19	12		23	58	16	2		16	56	21	7	P
46	7		17	28	46	9		7	59	30	7	
30	11		17	51	25	5		18	54	23	4	Q
32	8		11	48	31	6		19	48	24	7	
13	9		43	46	11	2		22	56	19	6	R
24	12		32	41	20	5		24	56	12	7	
25	13		19	38	25	6		25	31	38	0	S
35	17		15	48	25	12		8	52	25	10	